Interferometric Imaging of the Sunyaev-Zeldovich Effect at 30 GHz

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Observations of the Sunyaev-Zeldovich (S-Z) effect have been attempted since the effect was first predicted 25 years ago. The effect is a spectral distortion of the 3-K cosmic microwave background radiation resulting from inverse-Compton scattering of the microwave photons as they pass through the hot x-ray-emitting gas in the extended atmospheres of clusters of galaxies. The spectral distortion appears as a temperature decrement at frequencies below 218 GHz (>1.4 mm) and an increment at higher frequencies. Although the magnitude of the effect is small (~1 mK at radio wavelengths), its promise of providing an independent estimate of the Hubble constant and of the peculiar motions of distant clusters of galaxies has continued to motivate increasingly sensitive observations. The first observations of the effect were made in the radio regime with single-dish telescopes. The reported results show considerable differences, reflecting the difficulty of the measurement. These observations illustrated the need for telescopes and receiver systems designed explicitly to minimize differential atmospheric emission and ground pickup.

Interferometric observations offer several advantages over those made with single dishes for detecting and imaging weak emission. An interferometer measures only the correlated signal received by separate telescopes. Furthermore, the correlations are performed after compensation for the changing differential delays introduced as the array telescopes track the celestial source. This synchronous detection ensures that a well-designed interferometer will not suffer from the systematic effects associated with atmospheric and ground emission that are so difficult to determine and control in single-dish observations. A further advantage of interferometry, especially for relatively low frequency observations, is the ability to image and then remove emission from point sources that otherwise contaminate the S-Z effect. Last, interferometry provides a two-dimensional image of the emission.

In this paper we present images of the S-Z effect obtained with the millimeter-wave array of the Owens Valley Radio Observatory (OVRO) outfitted with centimeter-wave receivers. Using an array designed for millimeter wavelengths at centimeter wavelengths is ideal for imaging the S-Z effect and alleviates most of the problems discussed above. Additionally, the two-dimensional layout of the array makes it possible to obtain good u, v coverage and high brightness sensitivity, even for equatorial sources.

Low-noise receivers utilizing cooled high electron mobility transistor (HEMT) amplifiers that operate from 26 to 36 GHz were built and mounted at the Cassegrain focus of each of the 10.4 m telescopes of the Owens Valley millimeter array specifically to image the S-Z effect. The telescopes operating at 28.7 GHz provide a 4 arc min (’) FWHM primary beam. The resulting 1.0 kλ minimum baseline allows imaging angular scales as large as 1.7’, although in practice angular scales only less than about 1.4’ are imaged well. At these frequencies the surface accuracy is better than $\lambda/100$, and the pointing accuracy is better than $\lambda/50$ of the primary beam. The observations were obtained with five elements of the array during the period of June 16 to July 9, 1994.

Three clusters were targeted for observations: CL 0016+16, Abell 773, and Abell 1704. Their selection was based on a combination of strong x-ray emission, small angular size, previously reported S-Z decrements, and position. Abell 773 and Abell 1704 are at similar distances, $z=0.197$ and 0.220, respectively, while CL 0016+16 is much more distant at $z=0.541$. The S-Z effect toward CL 0016+16 is believed to be strong. The OVRO array is well suited to observations of CL 0016+16 since it allows reasonable u, v coverage at declination 16 degrees, and the 1’ synthesized beam is better matched to more distant clusters. The S-Z effect toward Abell 773 was observed by others with the Ryle telescope with a resulting signal-to-noise ratio (S/N) of ~5. We observed it to test our system and to provide a confirmation of their 15 GHz interferometric result. Unsuccessful searches for the S-Z effect toward Abell 1704 have been made by others; we also obtained a null result.

The full paper presents imaging results for each cluster. A decrement and associated sidelobes were clearly detected. In reference 2 an illistration shows our 56.5 in by 51.2 in resolution S-Z image overlaid on an x-ray image taken with the Roentgen Satellite (ROSAT) PSPC instrument, which has a resolution of ~30 in. The bright x-ray emission to the north of the cluster is from an active galactic nucleus (AGN) at $z=0.554$. The overall similarity of the two images is striking; the positions agree within the uncertainties, and both images show resolved structure elongated at a position angle of ~50 degrees. While the images give an impression of the data quality, quantitative information is best obtained by directly fitting models to the visibility data.

Using the core radius and ellipticity derived from the x-ray data to constrain the model parameters resulted in a decrement for CL 0016+16 of $\Delta T_0=-717\pm 65\ \mu K$. Measurements of the S-Z effect can lead to a determination of the Hubble constant and other cosmological parameters. However, a sensitive, unbiased imaging survey of galaxy clusters at both microwave and x-ray wavelengths will be necessary to achieve a reliable determination of these parameters. The results presented here demonstrate the power of using the OVRO millimeter array equipped with centimeter receivers to obtain high S/N images of the S-Z effect toward distant clusters. With the goal of conducting a survey of clusters, we have made several improvements to increase the sensitivity and imaging speed of the instrument.

[1]Carlstrom, J.; Joy, M.; Grego, L.: Astrophysical Journal Letters, 456, 75.

[2]Carlstrom, J.; Joy, M.; Grego, L.: Astrophysical Journal Letters, 461, 59.

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